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1 **METHOD FOR DIAGNOSING OPERATING STATES OF A SYNCHRONOUS**
 PUMP, AND DEVICE FOR CARRYING OUT SAID METHOD

5 This invention relates to a method for diagnosing operating states of a
synchronous pump in a liquid circuit, particularly in a dishwasher or similar.

10 Dishwashers often make use of synchronous pumps, that is pumps driven by
synchronous motors, to pump the water used for washing back from the
bottom of the interior of the appliance to the spray arms, thereby creating a
closed liquid circuit. This arrangement is widely used in order to save fresh
water.

15 In an ideal case, the volume of circulating water remains constant, and the
synchronous pump used to circulate the water works at a constant output.
Problems can occur, however, if water becomes trapped at points inside the
machine from which it cannot flow away, or be pumped away, and hence is
no longer available to be recycled to the spray nozzles. Such liquid reservoirs
are created, in particular, by saucepans or similar containers which tip over
during washing so that they finish up with their open ends facing upwards
20 and collect the water which is directed downwards onto the items to be
cleaned. Another problem is caused when water is prevented from circulating
due to clogging of the filter disposed in the floor on the inside of the
appliance at the inlet of the feed line of the synchronous pump. If the volume
of circulating water falls below a certain minimum, the incident-free
25 functioning of the appliance can no longer be guaranteed. Irrespective of the
fact that dirty objects are not cleaned as they should be, there is a risk in
this case of damage to the synchronous pump.

30 Hence it is desirable to be able to determine the momentary operating state
of the water circuit and, in particular, to ascertain that the pump is
functioning correctly. Methods are known for measuring the volume of water
fed into the circuit prior to the washing process. It is possible, for example,
to convey the water via a wheel which will then rotate at a speed proportional
to the volume of water conveyed across it. The advantage of this arrangement
35 is that it is inexpensive, but the results are relatively inaccurate. There is no
permanent monitoring of the volume of water in circulation whilst the
machine is in operation.

1 Document DE 196 30 357.5 A1 discloses a device for controlling the volume
of water in a dishwasher, whereby the torque of the synchronous motor
driving the pump is monitored to determine the operating state of the
synchronous pump. For this purpose the power uptake of the stator winding
5 is measured and a dosing valve for supplying the water for washing is
controlled as a function thereof, thereby guaranteeing permanent monitoring
of the volume of water in circulation.

Document DE 24 15 171.1 A1 further discloses the measuring of the
10 operating state of a synchronous motor by means of the phase shift between
the alternating voltage applied to the motor and the alternating current. A
momentary phase shift can then be assigned to a particular operating state.
The prior art solution is directed towards providing a means of monitoring
the operating state of synchronous machines with asynchronous start-up,
15 and of signalling asynchronous functioning. The intention is to economise
the costly and generally used method of measuring the speed of rotation,
replacing it with a less expensive means of monitoring. For the particular
application on which this invention is based, however, this method is only
suitable to a very limited degree as not all the operating states of a
20 dishwasher can be unambiguously identified by this prior art method. This is
particularly true of the above-described problems in connection with a liquid
circuit.

The task of this invention is, therefore, to provide a method for diagnosing
25 operating states of a synchronous pump of the type described above, the goal
of said method being to ensure the easiest, most reliable and most cost-
effective means possible of detecting and identifying a variety of operating
states of the synchronous pump corresponding to malfunctions in the liquid
circuit, in particular a fall in the volume of water in circulation below a
30 minimum level and clogging of the filter.

This task is solved according to the invention by means of a method
according to claim 1.

35 In the method according to the invention, an initial measurement step
involves taking at least one measurement of the alternating voltage applied
to, and the alternating current through, the motor. In a subsequent

1 determination step, the extent of a phase shift occurring between the
alternating voltage and the alternating current is measured. The phase shift
ascertained is used in a subsequent assignment step to identify a pump's
operating state.

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This diagnostic method is based on the knowledge that the phase shift
between the voltage and the current of the synchronous pump can be used as
an indicator of a pump malfunction. If, for example, a certain volume of
water is withdrawn from the dishwasher water circuit, say by an upturned
10 saucepan, there will be a change in the phase shift due to the occurrence of
an air-water mix in the pump housing. Action can then be taken to correct
the malfunction. The volume of water in the circuit can be topped up with
fresh water, for example. It may also be possible to trigger a warning signal
to alert an operator. All the steps in the method are relatively simple and
15 inexpensive to execute, on top of which the phase shift measurement is
reasonably accurate compared to conventional methods. Ongoing monitoring
of the water level means that fresh water can be added exactly as required,
thereby achieving a resources-saving water circuit. An additional energy-
saving effect is achieved in that only the water in the circuit need be heated
20 for the individual washing cycles.

In a preferred embodiment of the method according to the invention the
extent of the phase shift in the assignment step is assigned to a
predetermined phase shift value range linked to a certain pump operating
25 state.

Furthermore, preferably in the determination step, the difference between the
measured extent of the phase shift and a saved predetermined phase shift
can be determined and in the subsequent assignment step this phase shift
30 difference is assigned to a pump operating state. In this case, the state of the
pump is identified not with reference to the measured extent of the phase
shift, but to its deviation from a predetermined target value.

In a preferred embodiment of the method, the determination step involves
35 measuring the extent of the phase shift at various intervals so that the
chronological progression of the phase shift can be determined from the
recorded measured values. A characteristic of the chronological progression

1 of the phase shift is ascertained for assignment to a predetermined pump
operating state in the assignment step.

The ascertained feature is preferably assigned to a predetermined
5 characteristic value range linked to a pump operating state.

The gradient of the slope of the chronological progression of the phase shift
is preferably determined in the determination step and in the assignment
step it is assigned to a predetermined slope value range linked to a pump
10 operating state. Here, then, the gradient of the slope of the chronological
progression of the phase shift is used to identify the pump operating state,
e.g. a clogged filter.

In a further preferred embodiment, the determination step comprises a
15 transformation step in which the chronological progression of the phase shift
is submitted to a Fourier transform and the amplitude of the Fourier
transforms in a predetermined frequency range is determined. In this case,
the assignment step serves to assign the previously ascertained amplitude to
a predetermined amplitude value range which is in turn linked to a pump
20 operating state.

Hence in this case, the analysis is conducted in the frequency range. If, for
example, the chronological progression of the phase shift exhibits high-
frequency signal components this may indicate that there is an air-water
25 mixture in the pump housing preventing the pump from operating at full
capacity.

The Fourier transform may preferably be a discrete Fourier transform (DFT)
or the special form of the DFT, the so-called fast Fourier transform (FFT).

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The determination of the chronological progression of the phase shift in the
determination step may preferably include a sliding averaging.

The measurement step may preferably include converting the measured
35 alternating voltage signal and the measured alternating current signal into
rectangular signals.

1 A device for carrying out the method according to the invention comprises a
microcontroller with a timer comprising a voltage inlet for recording a start
signal and a current inlet for recording a stop signal. These voltage and
current inlets are configured to interpret the exceeding of a predetermined
5 voltage or current level as a start or stop signal. The content of the timer is
proportional to the chronological gap between the start and stop signals. The
microcontroller further comprises a memory for recording the timer content.

The timer of the above-mentioned microcontroller can be used to measure the
10 extent of the phase shift. The content of the memory, which is accessed by
other analytical devices, is proportional to the phase shift so that the device
according to the invention offers a simple means of analysing the pump
operating state.

15 In one preferred embodiment the memory comprises a number of memory
cells for saving a sequence of memory contents.

Furthermore, the microcontroller comprises an evaluation unit for averaging
the memory contents.

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An interface preferably serves to transmit operating state-related data from
the microcontroller to a control unit to control the liquid circuit.

The invention can also be applied to suitably constructed washing machines
25 or other machines that operate in circulating mode.

A preferred embodiment of the invention will be described in more detail
below with reference to the drawings, in which

30 Fig. 1 is a diagrammatic illustration of the voltage and current
signals to be measured and their transformation;

Fig. 2 is a diagrammatic illustration of the progression of the
phase shift;

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Fig. 3 is a diagram showing the function units of a device for
carrying out the method according to the invention;

1 Fig. 4 to 7 show the chronological progression of the phase shift in
line with various pump operating states; and

 Fig. 8 is a flow diagram explaining the method steps according
5 to the invention.

Fig. 1 shows four diagrams, each illustrating the progression of voltage and
current signals against time t . The top left diagram shows the sinus-shaped
path of the voltage U applied to a synchronous pump of a liquid circuit,
10 whilst the bottom left diagram shows the path, also sinus-shaped, of current
 I . Both sinus curves of voltage signal U and current signal I are out of phase
in relation to each other by a phase shift, that is corresponds to a
chronological shift between the zero crossing of current signal I with respect
to voltage signal U . The extent of this phase shift can be used according to
15 the invention to diagnose a pump operating state as will be explained below.
For this purpose the voltage U and current I applied to the motor are
measured in one measurement step and the extent of phase shift is then
determined in a determination step. Before further evaluation the measured
voltage and current signals U, I are first processed by means of conversion
20 into rectangular signals U' and I' . These signals are shown in a top and
bottom diagram on the right-hand side of Figure 1. In detail, the voltage
signal U is converted into rectangular signal U' by an optocoupler which
converts the analogue sinus-voltage signal U into a digital rectangular signal.
This produces a simultaneous potential separation between the motor voltage
25 and a downstream microcontroller used for evaluation purposes. To convert
the sinus current signal I into rectangular signal I' , the motor current is
conducted over a shunt as measuring resistance and the measuring voltage
is converted into a rectangular signal by means of an operational amplifier.
In this case, too, the potential separation is ensured by means of a
30 downstream optocoupler.

Figure 2 shows these processed signals U', I' together. Here, too, the abscissa
corresponds to time t , whilst the ordinate corresponds to the amplitude of
the signals. In the pump's normal operating mode in which it is completely
35 filled with water, a certain phase shift 1 occurs. If water is removed from the
water circuit in a dishwasher causing a decrease in the volume of water
conveyed by the synchronous pump, the phase shift 2 between voltage and

1 current signals $U'I'$ increases considerably as soon as the volume of water
falls below a certain level. This increase in the phase shift can be determined
in a determination step which follows on from the previously described
measurement step, and then used to determine the operating state of the
5 pump. For this purpose the measured extent of the phase shift can be
assigned in a subsequent assignment step to a value range which again
corresponds to a predetermined operating state. One may elect to start by
determination the difference between the measured extent of the phase shift
and a predetermined phase shift value, corresponding, for example, to a
10 measured extent 2 of the phase shift as per Fig. 2 and a value 1 in problem-
free normal operating mode, and this difference in phase shift is assigned to
a diagnostic operating state.

In a preferred embodiment of the method which will be considered in more
15 detail below, the chronological progression of phase shift is determined by
measurement at different points in time. This offers extensive possibilities in
terms of analysing the progression of the phase shift and of examining it for
characteristic features. A certain characteristic such as the extent of an
ascertained parameter in the chronological progression of phase shift can be
20 assigned to a predetermined pump operating state in an assignment step
which follows on from the determination step. This assignment may also
involve assigning, i.e. classifying, the characteristic to a predetermined
characteristic value range linked to a pump operating state.

25 The block diagram in Figure 3 shows functional components of a device for
carrying out this method. A microcontroller 10 comprises a timer 12 with a
voltage inlet 14 and a current inlet 16. The voltage inlet 14 serves to record
the rectangular voltage signal U' , whilst the current inlet 16 serves to record
the rectangular current signal I' . For this purpose the rectangular signals are
30 adjusted to the level of microcontroller 10. The rising slope of voltage signal
 U' serves as a start signal for timer 12 whilst the rising slope of current
signal I' serves as a stop signal. The content of timer 12, which is saved in a
memory 18 of microcontroller 10, is proportional to the chronological gap
between start and stop signals, and hence proportional to the phase shift
35 between these signals.

1 Memory 18 may comprise a number of memory cells which serve to store a
succession of memory contents. This makes it possible to determine the
chronological progression of phase shift over time t . Hence it is possible,
within a certain timeframe t , to conduct a number of phase shift
5 measurements, with each measurement corresponding to one memory
content at one memory position of memory 18. These measured values are
then subjected to sliding averaging with the help of a software module 20 of
microcontroller 10. The result is a smoothed chronological progression of
phase shift which can be examined for certain characteristics or parameters.
10 The advantage of sliding averaging is that it dampens the impact of
measurement errors. Furthermore, it is also possible in this manner to
analyse the characteristics of the phase shift progression after each new
measurement process.

15 The device may further comprise an interface for transmitting operating
state-related data to a water circuit controlling or regulating unit, such as a
hardware interface of microcontroller 10 for communicating with an external
control module. If microcontroller 10 itself serves to regulate the water
circuit the communication is accomplished internally by a software interface
20 for exchanging data between the appropriate software modules.

Figures 4 to 7 show chronological progressions of phase shift over time t
according to different operating states of the synchronous pump. The curves
shown are derived from a large number of measured values corresponding to
25 memory positions of memory 18, processed by software module 20 in the
manner described above. Figure 4 shows the start-up phase of the
synchronous pump. In a first time range t_1 there is a brief increase in the
phase shift. The chronological progression in this range t_1 also exhibits high-
frequency signal components. In the subsequent time range t_2 , a relatively
30 small, constant phase shift without high-frequency signal components is
established. This corresponds to the normal operating state of the pump with
a sufficient volume of water in the circuit, corresponding, for example, to a
sufficiently high level of water in a dishwasher.

35 Figure 5, on the other hand, shows the chronological progression of phase
shift as the water is pumped away, whereupon air enters the pump housing.
A first time range of the curve t_2 corresponds to the normal operating state

1 of the pump with a sufficiently high level of water as already shown in Figure
4. The phase shift in this time range t_2 is relatively small. But if additional
air enters the pump housing causing an air-water mixture, the phase shift
in time range t_3 increases very rapidly and high-frequency signal components
5 become established. The progression seen in time range t_3 also occurs if a
small amount of water is withdrawn from the water circuit (e.g. if a saucepan
turns open-end upwards).

If the pump housing empties gradually during time range t_4 , the phase shift
10 gradually increases from the almost constant value maintained in t_3 until
finally, in time range t_5 , a constant high phase shift value is reached which
corresponds to the complete emptying of the pump housing. This occurs
when all the water is completely drained out of the circuit.

15 As can be seen from Figure 5, different operating states of the pump
correspond to different chronological progressions of phase shift. This
means it is possible to draw conclusions as to the current operating state by
examining the phase shift. In particular, it is possible to investigate certain
parameters of the chronological progression of phase shift and its extent at
20 certain points, such as the gradient of the curve that is ascertained. If one
looks, for example, at time range t_4 in Fig. 5, one sees an approximately
linear progression in the phase shift over time t . If one determines the slope
 S_1 at a certain point in time, this slope S_1 can be assigned to a certain pump
operating state; in this case to a gradually emptying of the pump housing. In
25 the assignment step the gradient of slope S_1 is then assigned, i.e. classified,
to a predetermined slope value range linked to a pump operating state.

A further possibility is to follow the determining of the chronological
progression of the phase shift with a transformation step in which the
30 chronological progression of the phase shift is subjected to a Fourier
transform. This allows investigation of the frequencies contained in the
progression of the signal, as these frequencies are indicators of certain
operating states. In time range t_3 , for example, during which an air-water
mixture occurs in the pump housing, there are high-frequency signal
35 components which do not occur in the normal operating state, so that the
occurrence of such frequency components is a clear indicator of a system
malfunction. Thus the amplitude of the Fourier transforms in a

1 predetermined frequency range is determined and in the assignment step the
amplitude ascertained is assigned to a predetermined amplitude value range
linked to a pump operating state. In this case, for example, the high-
frequency components caused by an air-water mixture in the pump housing
5 will occur within a predetermined range of amplitude values, thereby
allowing categorical classification of the previously ascertained amplitude of
the Fourier transforms. The Fourier transform may be a discrete Fourier
transform (DFT) or the special form of the DFT, the so-called fast Fourier
transform (FFT), which can be calculated by software module 20 of
10 microcontroller 10.

Other characteristic signal progressions will be described below.

Fig. 6 shows the chronological progression of phase shift in the event of
15 filter clogging preventing a sufficient supply of water to the pump feed.
Starting from the normal pump operating state in time range t2, the filter
clogging builds up, leading to a gradual increase in phase shift until the
filter is completely clogged (time range t7) and the phase shift attains a very
high, constant value. The slope S2 in time range t6 is thus an indicator of
20 the occurrence of continuous filter clogging. To diagnose this operating state
one therefore determines, in the determination step in the manner described
above, the gradient of slope S2 of the ascertained chronological progression
of phase shift, and in the assignment step the ascertained gradient of slope
S2 is assigned to a predetermined slope value range, which, in this case,
25 corresponds to the operating state associated with continuous filter clogging.

Complete clogging of the filter (time range t7) can also occur all of a sudden if
a foreign body enters the filter. This case is depicted in time ranges t8 and
t9. Whilst the pump operates normally with a small phase shift during time
30 t8, there is a sudden increase in the phase shift in the event that the foreign
body enters the filter, so that a very high constant phase shift is attained in
time range t9. Both operating states can be ascertained with the help of one
of the above-described diagnostic methods.

35 Finally, Figure 7 shows a case in which the synchronous motor of the pump
is in one of its two dead points and fails to start up. This operating state is
also diagnosable since in this case the phase shift signal attains a very high

1 constant value without any high-frequency signal components occurring. For
example, the lack of high-frequency signal components offers a possibility for
diagnosis in that the above-described Fourier transform is performed and the
progression of the amplitude of the Fourier transforms is examined.

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The flow diagram in Fig. 8 summarises the individual steps of the method. In
measurement step 30 the alternating voltage U applied to the motor and the
motor alternating current I are measured and converted into rectangular
signals U' , I' . In the subsequent determination step 32 the extent of the
10 phase shift between the alternating voltage U' and the alternating current I'
is determined, the chronological progression is ascertained and sliding
averaging is performed. In this determination step 32 one may also examine
a parameter of the curve that is ascertained, e.g. the extent of the slope. The
subsequent assignment step 34 then serves to classify the ascertained
15 characteristic, e.g. the gradient of the curve, i.e. to assign it to a
predetermined range of values linked to a pump operating state which may
correspond to a malfunction of the synchronous pump. It is optionally
possible that determination step 32 includes the above-mentioned
transformation step for frequency analysis by means of Fourier transform,
20 and the amplitude of the Fourier transforms is classified in assignment step
34. Four such to-be-assigned operating states 36,38,40,42 are shown on the
right-hand side of Fig. 8, namely the successful start-up of the synchronous
pump, the aspiration of air if the water level is low, the non-conveyance of
the pump if the filter is clogged and the failure of the pump to start up.

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The diagnostic method according to the invention and the corresponding
device are particularly well suited to use in dishwashers, but are not limited
to this. The invention can easily be used in connection with liquid circuits of
other types requiring, during operation, ascertainment of certain operating
30 states of the synchronous pump and diagnosis of malfunctions.

Merely ascertaining the phase shift between voltage and current in a single
measuring point delivers information about the operating state of the motor
with regard to a certain parameter such as the load moment. Other
35 ascertainments are rendered possible if the chronological progression of the
phase shift between voltage and current is established by means of several
successive measurements. The invention includes both variants of the

1 measuring method. It is, however, also possible to carry out the method so
that only one of the two measuring methods is used. Both methods therefore
have independent importance.

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